Results from a search for secluded dark matter in the Sun using 6 Years of IceCube data

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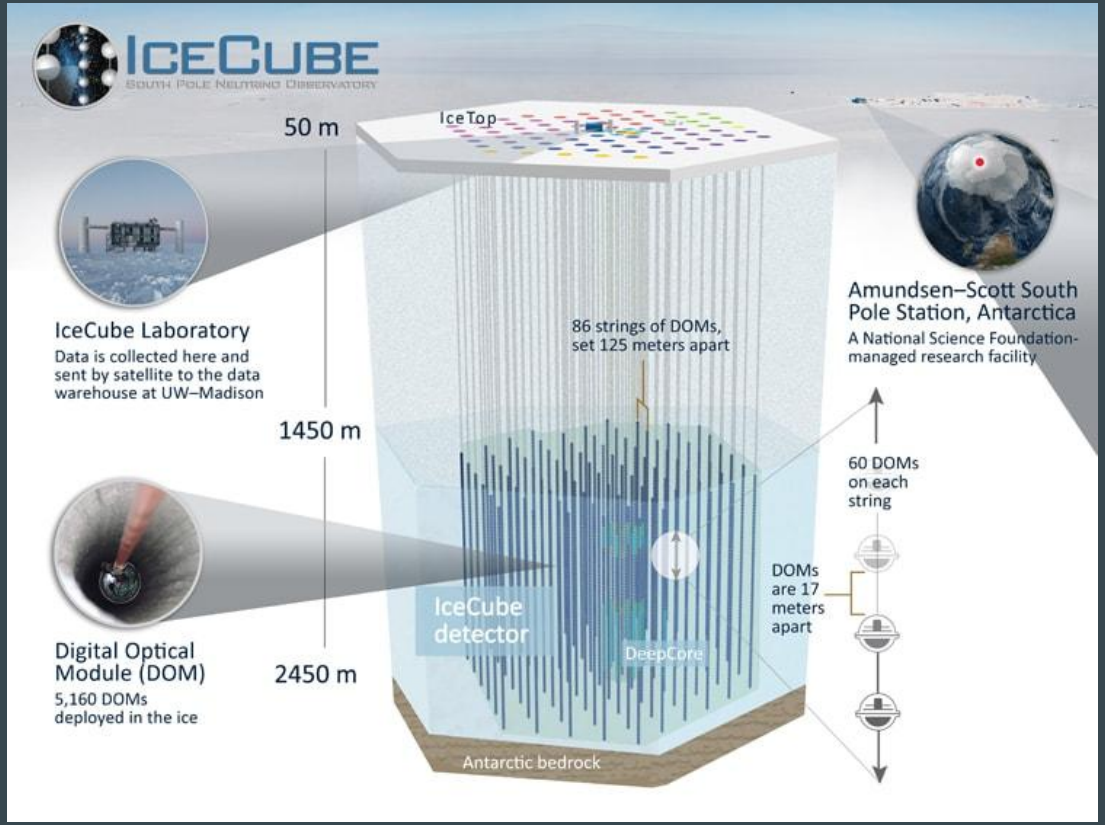
IceCube
South Pole Neutrino Observatory

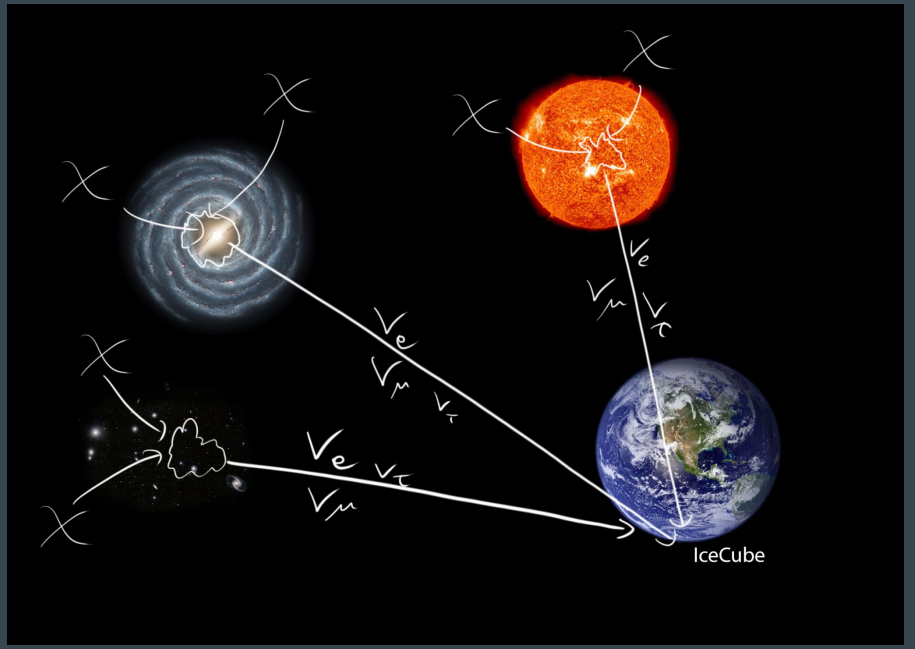
IceCube

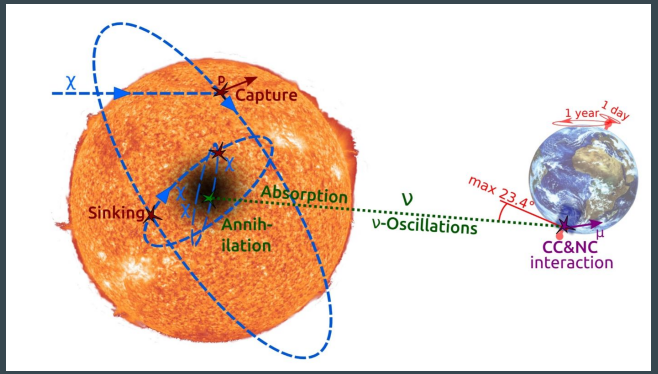
- IceCube is the world's largest neutrino telescope
- Neutrinos are detected through the cherenkov light that is generated when relativistic particles created as a result of the neutrino interaction pass through the detector medium. Event topologies allow for the identification of the neutrino flavor:
  - Tracks indicate muon neutrinos
  - cascades indicate electron and tau neutrinos
- It detects this light using a 3D array of photomultiplier tubes inside so-called digital optical modules



Types of DM searches in IceCube

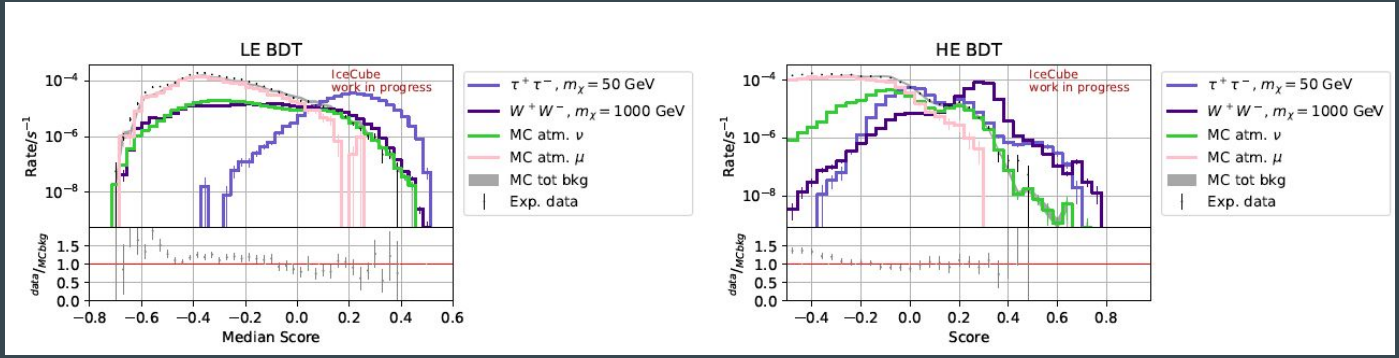
- Using IceCube data different types of searches for dark matter can be conducted:
  - Searches toward the Sun
  - Searches toward the Galactic center or extragalactic objects
  - Searches towards the earth
- In this presentation we will focus on searches in the earth and Sun
- In these searches a local overabundance of DM accumulates due to scattering and gravitational capture in the Earth/Sun
- Searches for High mass dark matter will be presented by M. Jeong





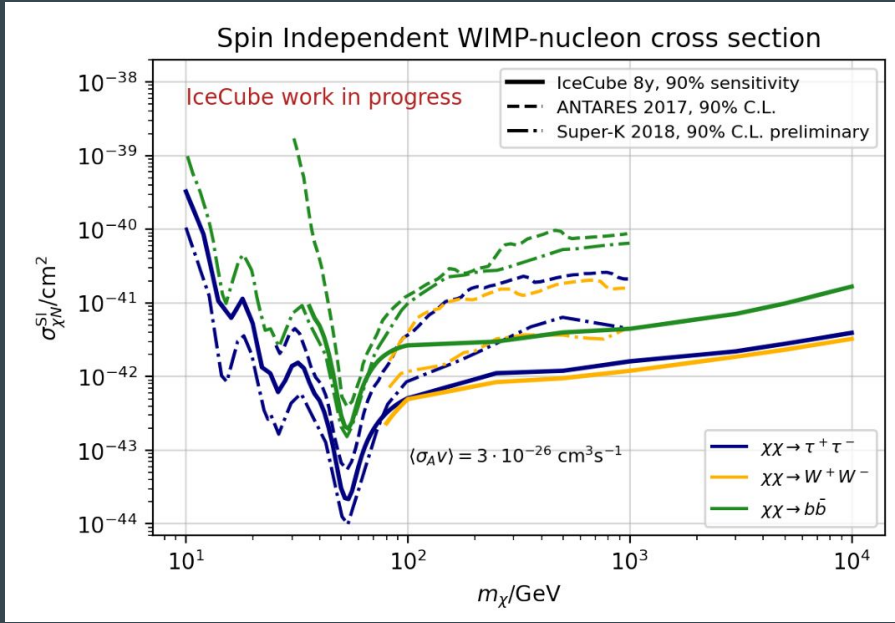
Earth dark matter search

- The most recent earth dark matter analysis uses an effective likelihood developed in (J. High Energ. Phys. 30 (2019))
- This method is a generalized form of a binned likelihood that takes uncertainties on the parameters of recorded events into account
- The analysis also uses separate event selections for low and high energy neutrinos employing boosted decision trees
- Both Earth and Solar dark matter searches are of particular interest as the amount of dark matter in both objects can be enhanced due to the impact of the dark disc part of the galactic DM halo by 2 to 3 orders of magnitude for the earth and 1 for the sun (Phys.Lett.B674:250-256,2009)



Dark matter in the earth

- In an earth dark matter search an equilibrium between accumulation and annihilation is not given, so that a certain thermally averaged annihilation cross section has to be assumed.
- Due to the different composition of the earth, such searches are more sensitive to spin dependent scattering compared to solar DM searches
- The most recent search used 8 years of IceCube data (PoS(ICRC2021)526)

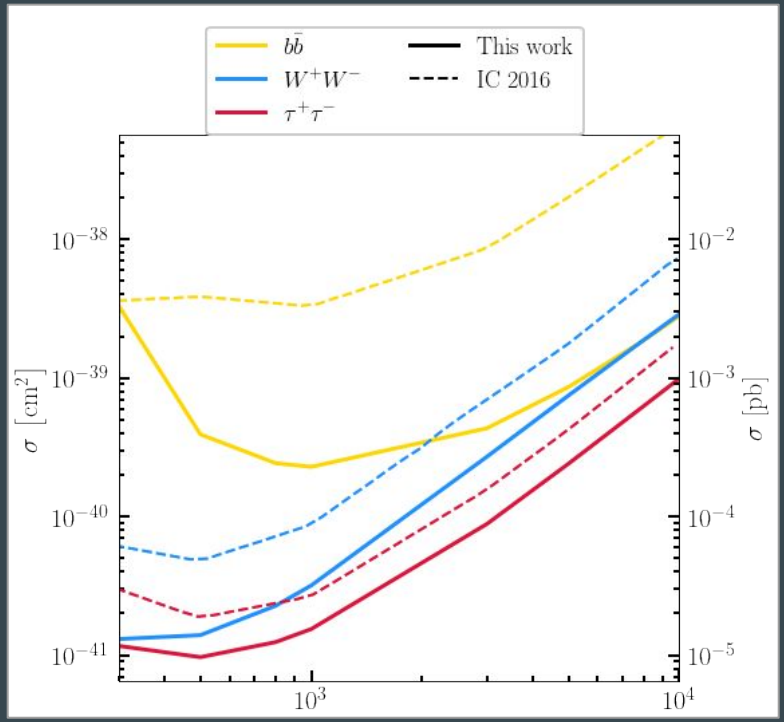


Solar dark matter search

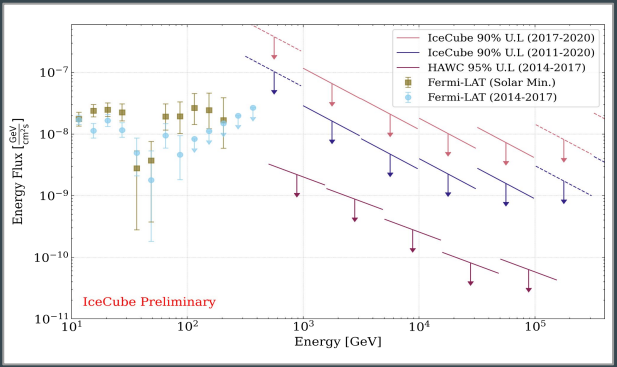
- Similar to the earth dark matter analysis the solar analysis employs separate neutrino event selections for low and high energies, but also a medium energy selection was introduced
- For low energies the OscNext event selection, that was originally developed for a wide suite of oscillation analysis was used
- The high energy sample uses 9 years of 86 string IceCube data and for neutrino energies around 100 GeV a sample generated with the ice cube ‘LowUp’ filter was used

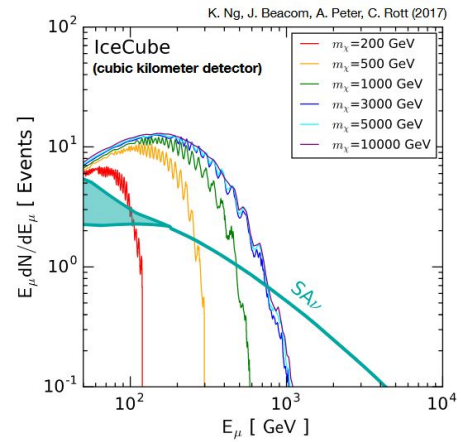
Results from Solar Dark Matter searches with IceCube

- In solar DM searches an equilibrium between capture and annihilation is assumed, allowing to set limits on scattering cross sections
- As the Sun consists mostly of hydrogen and helium the capture of DM in the Sun is dominated by Spin dependent scattering
- The most recent results from IceCube use 9 years of data (PoS(ICRC2021)020) and apply separate optimizations at high and medium energies
- This current analysis uses simulated dark matter neutrino spectra that include electroweak corrections that yield a strongly enhanced flux for the bb channel



Solar atmospheric neutrinos

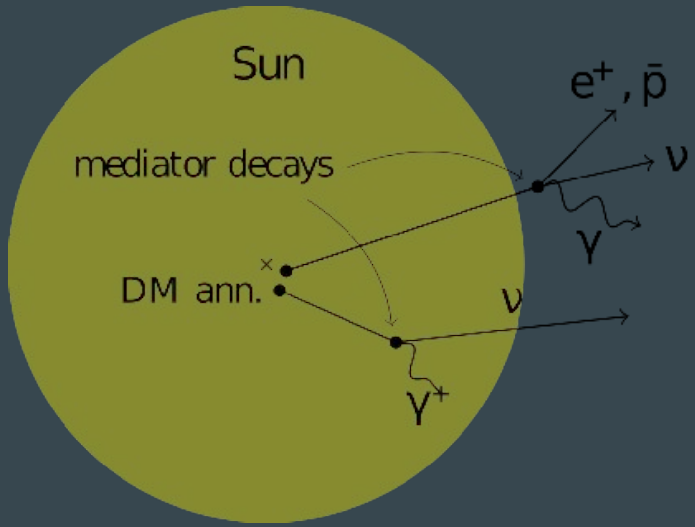




- One significant background for solar dark matter searches are solar atmospheric neutrinos
- These are generated when cosmic radiation interacts with the solar atmosphere
- The spectrum predicted for this radiation (C. Argüelles, G. de Wasseige, A. Fedynitch, B. Jones JCAP 1707 (2017) no.07, 024; K. Ng, J. Beacom, A. Peter, C. Rott Phys.Rev. D96 (2017) no.10, 103006; J. Edsjö, J. Elevant, R. Enberg, and C. Niblaeus, JCAP 2017.06 (2017), p. 033; M. Masip Astropart.Phys. 97 (2018) 63-68) is similar to the expected dark matter neutrino spectra and creates a sensitivity floor for neutrino-based dark matter searches in the sun
- This radiation was recently studied using the IceCube detector.

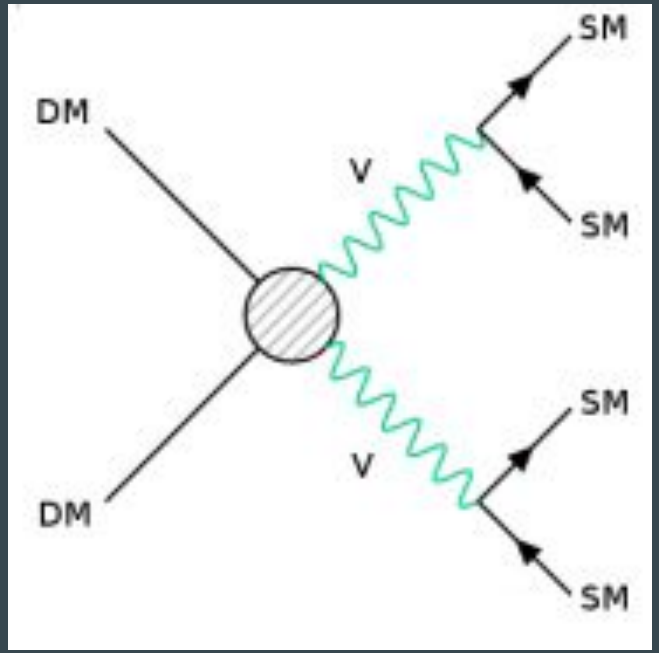
Secluded dark matter

- Secluded dark matter is a unique type of model for dark matter
- In this model Dark matter particles do not directly decay or annihilate into standard model particles
- Instead in dark matter annihilations metastable mediators are produced
- After a lifetime that can range from microseconds to 10 seconds the mediator decays into some standard model particle
- This mediator is itself not a standard model particle and can avoid interactions with baryonic matter
- In case of annihilations of dark matter accumulated in the Sun absorption in the solar plasma can be avoided



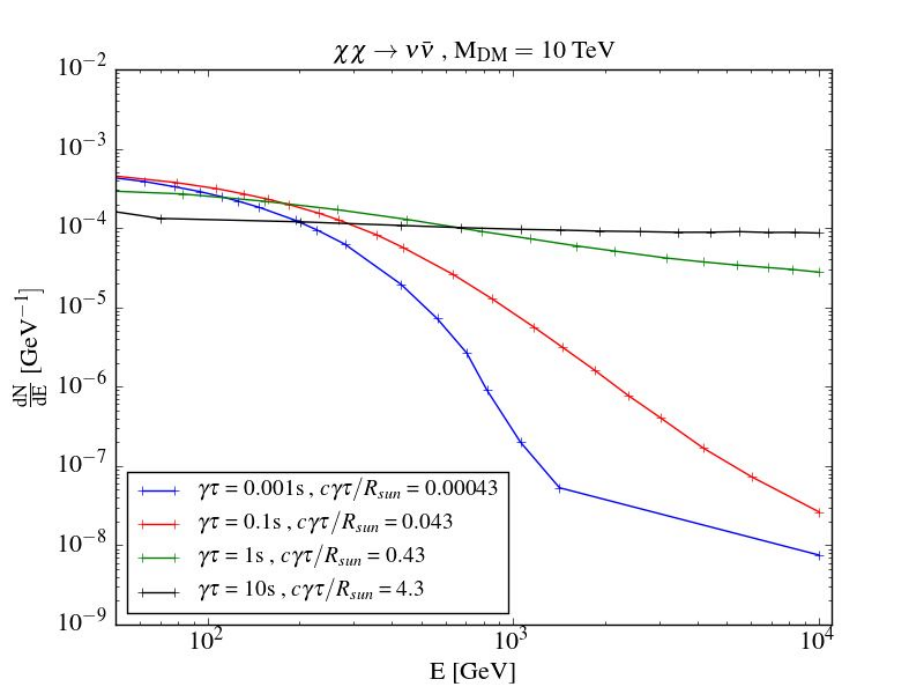
Theoretical motivation

- Secluded dark matter is theoretically well motivated
  - Can explain the positron excess detected in PAMELA, AMS-II and FERMI (F. Chen, J. M. Cline, A. R. Frey, Phys. Rev. D 80 (2009) 083516.)
  - Many dark matter models naturally include a mediator like dark photons or Z' models (M. Pospelov, A. Ritz and M. B. Voloshin, Phys. Lett. B 662 (2008) 53. ; I. Z. Rothstein, T. Schwetz and J. Zupan, JCAP 07 (2009) 18.)
  - Secluded dark matter models decouple dark matter scattering and annihilation and allow to explain accelerator results



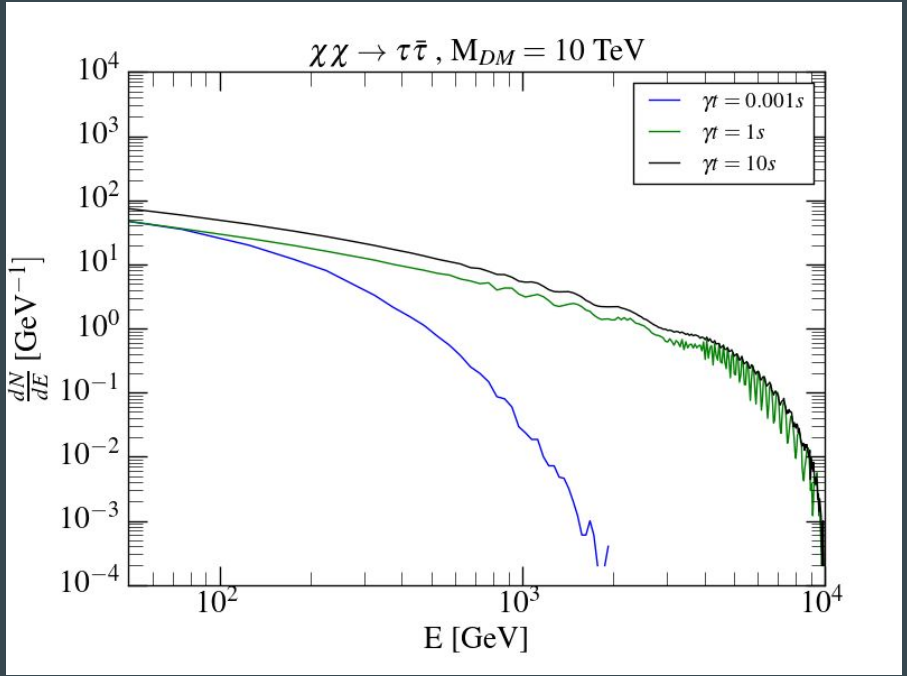
This analysis

- This analysis looks for secluded dark matter in the Sun
- Due to absorption in the Sun neutrino signals are strongly reduced at all energies
- Beyond 1 TeV of energy almost all neutrinos are being absorbed
- For lifetimes above 2.3 s mediators generated by dark matter in the Sun will escape the Solar plasma before decay
- In such a case the neutrino signal would be significantly enhanced, especially at energies above 1 TeV



WIMPSIM spectra

- Spectra have been generated for dark matter masses of up to 75 TeV and cover dark matter decays into W-bosons and tau leptons
- Other channels were not used a s in WIMPSIM there is no implementation for the BRW electroweak correction
- Different masses of the mediator ranging from 1 GeV to 1 TeV were simulated
- Mediator decay lengths from 0.001 solar radii to 10 solar radii wer used
- The spectra include effects from neutrino oscillations



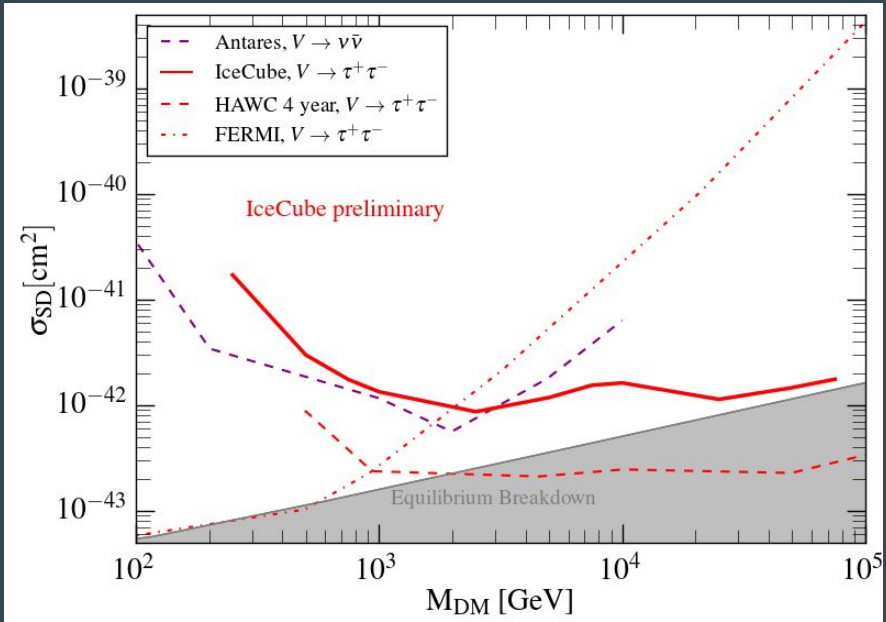
Method

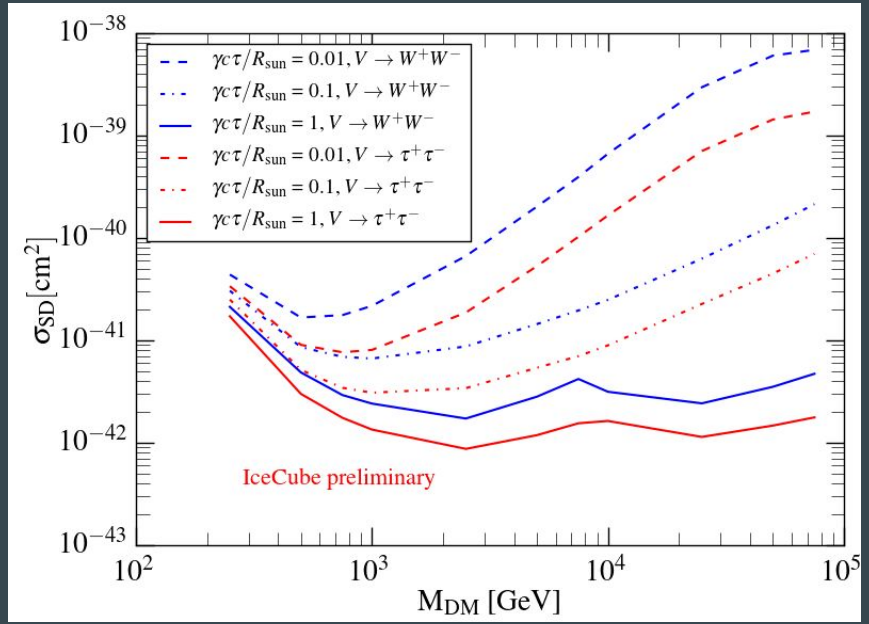
- An unbinned likelihood method is used
- The likelihood function has the following shape:

$$\mathcal{L}(n) = \prod_{i=0}^{N} \left(\frac{n}{N} S(\psi_i, E_i) + \frac{N-n}{N} B(\psi_i, E_i) \right)$$

- N is the sample size, S describes the signal behaviour as a function of the angular separation of an event to the Sun ψ_i and its energy E_i for event number i. B is the corresponding function describing the background.
- The background part of the likelihood is generated from time scrambled data
- Using this likelihood the IceCube northern tracks sample from 2011 to 2016 with 1057.8 days of livetime is being analysed

Limits





No significant excess above the expected background was found in the examined dataset. The set limits are the best of any current neutrino experiment above 3 TeV accounting for differences in mediator decay channel.

Summary

- The IceCube collaboration has set some of the strongest limits on Dark Matter models from neutrino experiments for a wide range of different models
- Limits for the earth and Sun using 6 years of data have been generated
- Solar atmospheric neutrinos, which are a significant background for solar DM searches have been investigated with IceCube data
- A first search for secluded dark matter of a 6-year set of IceCube data has been completed
- The best limits for secluded dark matter from neutrino experiments above 3TeV DM mass were set
- An update to the analysis using 9 years of data is underway